# Quantifying relationships between measures of extra-tropical cyclone intensity

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28.6.2023

This research was supported by the Academy of Finland (grant no. 338615)

# CONSISTENT INTENSITY QUANTIFICATION IS NECESSARY

- Extra-tropical cyclones (ETC) cause most of the variability in weather in the mid-latitudes and can cause significant damage to infrastructure

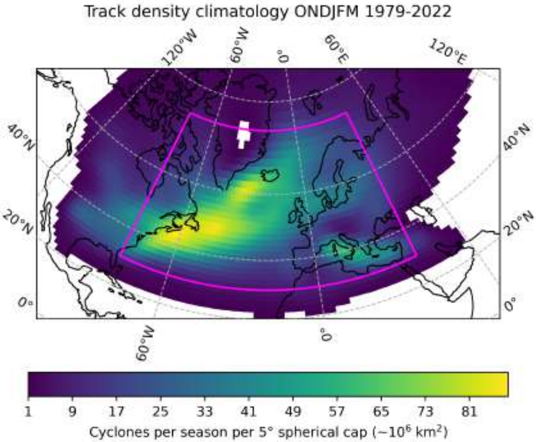
- There is a need to consistently quantify the intensity of extra-tropical cyclones to
  1. describe ETCs in the current climate
  2. compare ETCs between different climates (*e.g.* future projections)
  3. compare ETCs between reanalyses
  4. identify historical temporal trends

# ETC INTENSITY QUANTIFICATION IS NOT STRAIGHTFORWARD

- ETC intensity can be quantified with many different measures
  - Dynamical intensity vs. impacts?
- Using only *e.g.* relative vorticity or mean sea level pressure (MSLP) is unlikely to fully describe ETC intensity
  - Weak ETC in terms of vorticity or MSLP can have significant impacts and vice versa
- What intensity measures are needed to comprehensively describe the intensity of ETCs?

# 43 WINTERS OF ETC TRACKS PRODUCED

- ONDJFM 1979–2022: ETC tracks in the North Atlantic and Europe
- Tracked with ERA5 3-hourly relative vorticity at 850 hPa using TRACK software
- Inclusion criteria for distance, duration, intensity and location
- In total ~7300 tracks meet the criteria



# 8 ETC INTENSITY MEASURES ANALYSED

- Intensity measures were analysed for each ETC around its centre
- 6 measures in a single grid point

| Measure | Type | Max distance (geodesic °) |
|---|---|---|
| 850-hPa vorticity | Max (T42) | 0 (centre) |
| MSLP anomaly | Nearest local min | 6 |
| 850-hPa wind speed | Max | 6 |
| 925-hPa wind speed | Max | 6 |
| 10-m wind speed | Max | 6 |
| 10-m wind gust | Max | 6 |

# 8 ETC INTENSITY MEASURES ANALYSED

- Intensity measures were analysed for each ETC around its centre
- 6 measures in a single grid point
- 2 measures summed over an area

| Measure | Type | Max distance (geodesic °) |
|---|---|---|
| 850-hPa vorticity | Max (T42) | 0 (centre) |
| MSLP anomaly | Nearest local min | 6 |
| 850-hPa wind speed | Max | 6 |
| 925-hPa wind speed | Max | 6 |
| 10-m wind speed | Max | 6 |
| 10-m wind gust | Max | 6 |
| Storm severity index | Sum over area | 10 |
| Wind footprint | Gust > 15 m/s area | 10 |

# Correlation analysis used for evaluating interchangeability of measures

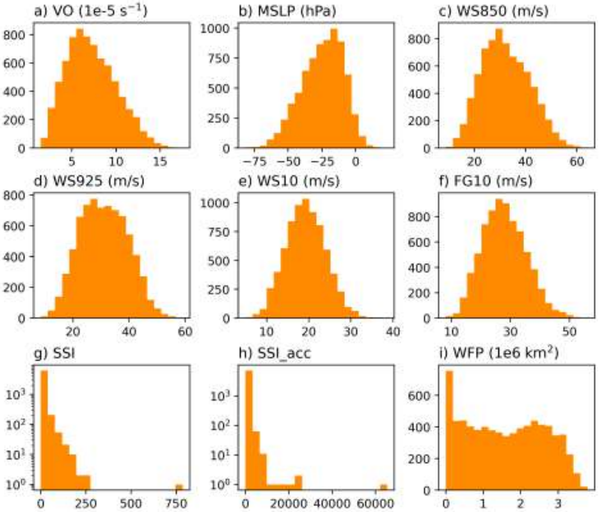
- For each track only the point at time of maximum vorticity was chosen for the analysis
  - Storm severity index (SSI) makes an exception: in addition to instantaneous SSI, an accumulated SSI was computed for each ETC by time-integrating instantaneous SSI over the whole track

- Correlation between intensity measures was quantified with
  1. Pearson correlation (linear correlation)
  2. Correlation from mutual information (also non-linear correlation)

- Strong correlation between intensity measures indicates redundancy

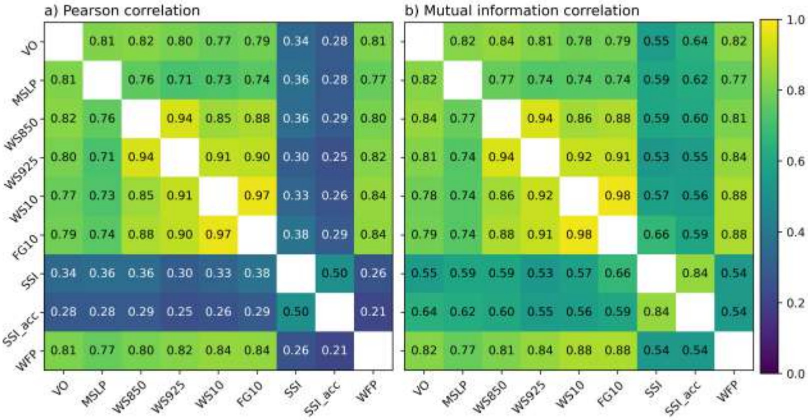
# SSI AND WIND FOOTPRINT SEPARATE TRACKS

- Vorticity, MSLP and winds all have a Gaussian-like distribution
- SSI values are heavily concentrated on very small values (count shown on a logarithmic axis)
- Wind footprint's distribution is relatively flat in the middle



# MEASURES ARE CORRELATED WELL WITH EACH OTHER, EXCEPT FOR THE SSIS

- Correlation between SSIs and other measures is non-linear
- Correlation is nearly linear between other measures
- Strongest correlations between wind measures

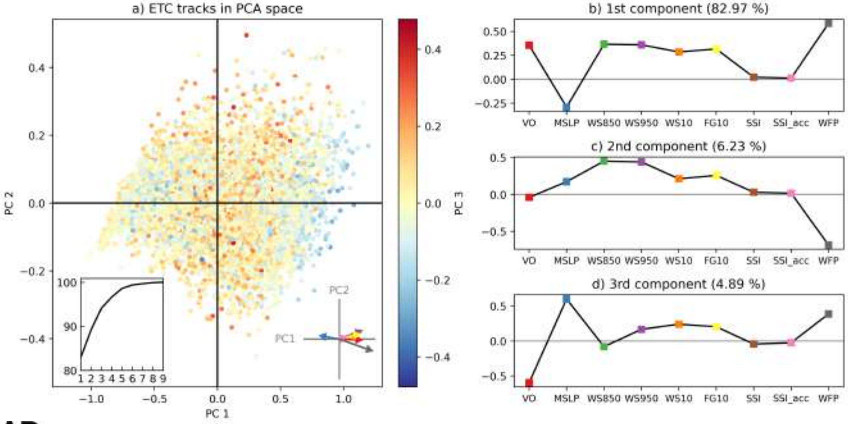


# Principal component analysis indicates which measures are "important"

- Principal component analysis (PCA) was used for reduction of dimensions – which set of intensity measures explain most of the variance in the dataset?
- Results of the PCA were used to guide Sparse PCA, which constrains the principal components to have a sparser expression
- The PCAs give each measure a weight between [-1,1] whose absolute value indicates the magnitude

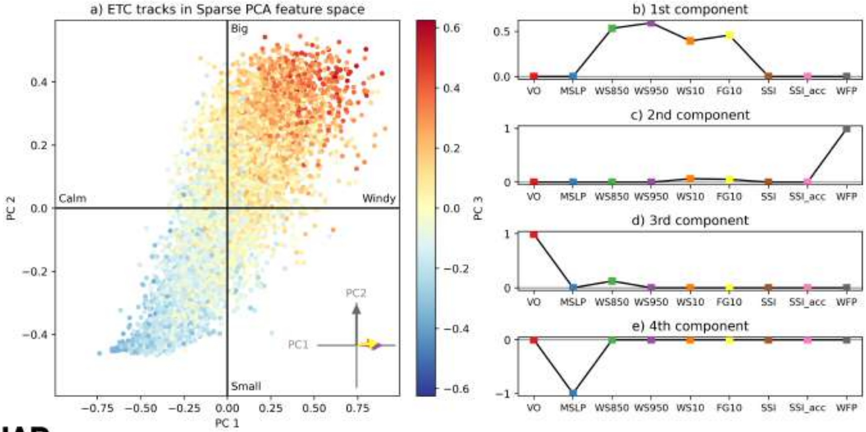
# PCA: Four first components explain almost 97 % of variance in the dataset

- WFP: largest weight in the first two components
- SSI: weight close to zero in all components
- Difficult to interpret physically
  → Sparse PCA



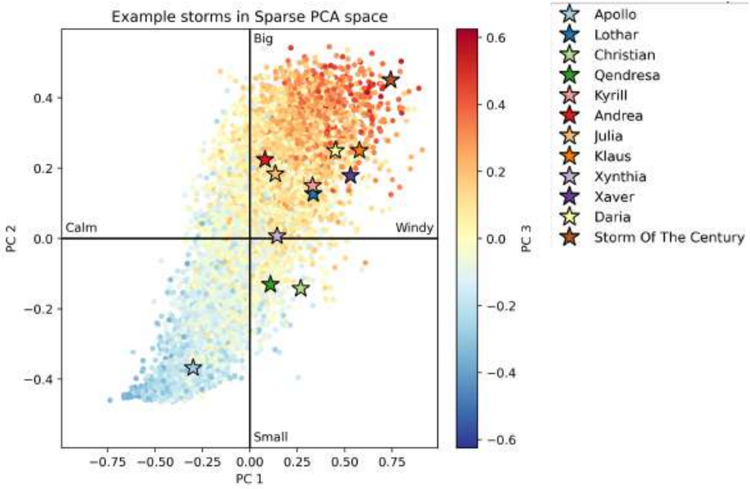
# SPARSE PCA GIVES PHYSICALLY INTERPRETABLE COMPONENTS

- All winds, WFP, VO and MSLP comprise the components, respectively
- WS850 covaries with VO and other winds
- SSI absent from all components



# NAMED STORMS IN SPARSE PCA SPACE

- Non-Mediterranean European storms: Lothar, Christian, Kyrill, Xynthia, Xaver, Daria
- Mediterranean storms: Apollo, Qendresa, Andrea, Julia, Klaus
- Storm of the Century impacted North America



# FOUR MEASURES CHOSEN FOR COMPREHENSIVE REPRESENTATION OF ETC INTENSITY

1. Wind footprint: stands out in the PCAs
2. 850-hPa vorticity: a traditional measure of intensity which according to the PCAs is a relevant feature; interchangeable with MSLP
3. 850-hPa wind speed: all wind speed measures are strongly correlated and grouped in the Sparse PCA, WS850 chosen to represent the winds because of its link to 850-hPa vorticity
4. SSI (instantaneous): is not present in the PCAs but is very uncorrelated with the other measures which means it is not "interchangeable" with them

# CONCLUSIONS AND PERSPECTIVES

- The aim was to investigate what intensity measures are needed to comprehensively describe ETC intensity
- A set of nine ETC intensity measures was produced and relationships between the measures quantified
- Out of the nine measures four are needed to exclusively describe a given ETC's intensity
- Next step is to use these four measures as input in a cluster analysis to produce ETC classes
  - Does the set of intensity measures produce ETC classes that are different and make physical sense?

# ACKNOWLEDGEMENTS

Thank you to:

- Kevin Hodges for providing the TRACK code and helping with ETC tracking
- Benjamin Doiteau and Florian Pantillon for collaboration especially in analysing the SSI
- COST Action MedCyclones for funding Benjamin Doiteau's STSM to Helsinki
- Clément Bouvier, Victoria Sinclair and the rest of the Dynamic Meteorology group at INAR

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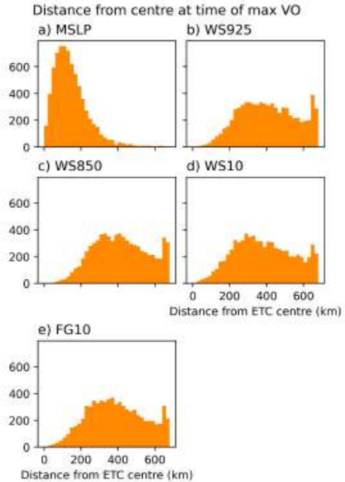
# 6 °BEST OPTION FOR DYNAMICAL MEASURES



# STORM SEVERITY INDEX IS BASED ON WIND CLIMATOLOGY

$$\mathrm{SSI}_{\mathrm{inst}} = \sum_{k} \max\left(0, \frac{v_k}{v_{98}} - 1\right)^3 A_k$$

- Storm severity index (SSI) adapted from Leckebusch *et al.* (2008)
- Normalised exceedance of 10-m gust speed climatology cubed and weighted by relative area of grid point in the area within 10 degrees from ETC centre
- Accumulated SSI is produced by time-integrating the instantaneous one

# MOST SSI WITHIN 10°

- On average most SSI is captured within 10°of ETC centre
- Accumulated SSI increases after 10°– contamination from neighbouring systems